Mechanical properties of WaveOne and ProTaper instruments in relation to torsion, hardness and tenacity

Cíntia Bueno de **PAULA**[1]
Victor Talarico **LEAL**[2]
Renata Gonçalves **SOARES**[1]
Hélio Pereira **LOPES**[3]

DOI: https://doi.org/10.14436/2358-2545.7.2.046-054.oar

ABSTRACT

Objective: This study evaluated the torsional fracture strength of two brands of machined NiTi instruments with different geometric shapes and produced with different metal alloys. **Material and Methods:** Fifteen WaveOne *Large* and fifteen ProTaper F4 instruments were selected and subjected to mechanical torsion, Vickers microhardness and toughness test. In the torsion test, angular deformation until fracture and maximum torque were evaluated. The fractured surfaces and helical rods of the instruments were analyzed by scanning electron microscopy (SEM). **Results:** The values of the maximum torsion torque (N/cm) was higher for WaveOne. The Vickers microhardness values were higher for the NiTi *M-Wire* alloy, while the control group showed higher toughness. Student's t-test showed a significant difference in the torsion tests ($p<0.05$), toughness and Vickers microhardness. SEM analysis revealed plastic deformation along the helical coils of all fractured instruments and ductile type fracture. **Conclusion:** The instruments manufactured in NiTi *M-Wire* presented higher resistance to fracture by torsion and microhardness, in comparison to those of conventional NiTi. Due to the higher torsion angle of the ProTaper and greater deformation to fracture, these parameters make this instrument safer from a clinical standpoint.

Keywords: Endodontics. Dental instruments. Alloys.

How to cite: Paula CB, Leal VT, Soares RG, Lopes HP. Mechanical properties of WaveOne and ProTaper instruments in relation to torsion, hardness and tenacity. Dental Press Endod. 2017 May-Aug;7(2):46-54.
DOI: https://doi.org/10.14436/2358-2545.7.2.046-054.oar

» The authors report no commercial, proprietary or financial interest in the products or companies described in this article.

[1]Unifenas, Curso de Aperfeiçoamento em Endodontia (Varginha/MG, Brazil).

[2]Universidade do Grande Rio, Programa de Pós-graduação em Odontologia (Rio de Janeiro/RJ, Brazil).

[3]Universidade Estácio de Sá, Programa de Pós-graduação em Odontologia (Rio de Janeiro/RJ, Brazil).

Submitted: August 30, 2016. Revised and accepted: January 17, 2017.

Contact address: Cíntia Bueno de Paula
Rua Professor Telles, 216 - Alpinópolis/MG
CEP: 37.940-000 – E-mail: cbpaulaonline@yahoo.com.br

Introduction

The main purpose of using endodontic files, chemicals and other solutions, together with irrigation and aspiration, is to clean and shape the root canal.[1] The persistence of some microbial species after instrumentation is a risk factor that may compromise the success of endodontic treatments.[2]

Stainless steel hand files have been used for root canal cleaning and shaping for a long time. However, NiTi rotary files are currently common in endodontics, as they have advantages over conventional stainless steel files: they are more flexible and have greater cutting efficiency.[3,4] Using superelastic NiTi rotary files, endodontists are able to prepare conical canals, as desired, with less transportation. Despite these advantages, NiTi rotary files seem to have a high risk of fatigue or torsional fractures.[3,5]

Oscillation has been developed to reduce the tension generated during filing, as well as to allow the use of a single file for all canal preparation, a characteristic that has raised great interest among dentists. In oscillation, the risk of torsional fracture is reduced because the rotary angles are smaller than 360 degrees (continuous rotation).[6] Recent findings in the literature[7] have demonstrated that oscillation may result in greater resistance to fatigue than continuous rotation.

Material and Methods

Thirty endodontic files were selected: 15 WaveOne Large (Fig 1) and 15 ProTaper F4 (control group) (Fig 2). All files had a nominal tip diameter of 0.40 mm and total length of 25 mm. ProTaper F4 files had a taper of 0.06 mm/mm, and WaveOne Large, a taper of 0.08 mm/mm in the 3 mm from the tip.

Ten WaveOne Large counterclockwise rotating files and ten ProTaper F4 clockwise rotating files (control group) were randomly selected, as suggested by Elias and Lopes.[8]

Torsion tests were used to evaluated angular deflection at failure and torque at failure. Torsion was applied by a device attached to a universal testing machine (EMIC, DL 10.000, Emic Equipamentos e Sistemas de Ensaio Ltda., São José dos Pinhais, Brazil) (Fig 3), which was used to control rotation and measure the loads applied to each file. Files were clamped at 3 mm from the tip by metal jaws. To prevent the induction of compressive stress on the file during torsion, a U-shaped part was used to allow the jaws that were clamping the file tip to slide, as necessary. The other end of the file was held by a chuck coupled to the rotating shaft. The distance from the point where the sample was clamped by the chuck to the point of load application was 22 mm (useful length of specimen).

Torsion was applied by a 0.3-mm nylon cord rolled around the rotating shaft of the universal testing machine, which measured 8 mm in diameter (r = 4 mm). This cord connected the rotating shaft to a 20 N load cell coupled to the crosshead of the universal testing machine. Torque was applied to the file by pulling the cord at a speed of 1 mm/s, and the shaft rotated at 2 rpm.[9]

Load and cord displacement until file failure were continuously recorded by a microcomputer coupled to the universal testing machine. The M test 1.01 software (Emic Equipamentos e Sistemas de Ensaio Ltda., São José dos Pinhais, Brazil) was used to determine angular deflection at failure and torque at failure. To determine angular deflection at failure, deformation at failure was calculated as: angular deflection at failure (degrees) = file deformation at failure x 360 / $2\varpi R$; angular deflection at failure in number of revolutions = degrees/360. Moreover, torque at file failure was calculated as: torque at failure (gf.mm) = maximum load (gf) x radius (mm). A radius of 4.15 mm was used in the calculation of angular deflection at failure and torque at failure. This value was the sum of the rotating shaft radius (R = 4 mm) and the cord radius (R = 0.15 mm).

A computer was used to determine toughness, defined as the area under a stress-strain curve (N.mm) and calculated using the OriginPro (OriginLab, Northampton, MA) software; file toughness at failure was calculated as the area under the curve using numerical integration.

Two files of each group were used for the Vickers microhardness test. They were embedded longitudinally in epoxy resin (Duque Fibras, Duque de Caxias, Brazil) and poured into PVC cylinders (Tigre DN 40 NBR 5688) previously coated with soft paraffin.

To evaluate the cross section, three vertically embedded files of each group were used. When embedding for the microhardness test, the file fixation shaft was parallel to the base of a container that held the file tip after sample preparation. To shape the files, 200, 300, 400, 600 and 1200-grit sandpaper (Norton, Worcester, MA) was used, and to polish them, 1, 0.5 and 0.25-μm alumina, followed by diamond paste, was used. After this initial preparation, the specimens were examined using a microindentation hardness tester (Micromet 2003, (Buehler, Lake Bluff, IL) (Fig 4) and a 1.0 N load for 15 s. The images were evaluated under 40 x magnification. Five indentations were made in the center and five in the intermediate area, at a total of ten indentations on each file examined.

For the analysis of cross-sectional shape of the files used in the study, three files of each group were examined under scanning electron microscopy (SEM) at the Military Engineering Institute of Rio de Janeiro (IME), Brazil (Fig 5).

Three broken files of each group were randomly selected for the examination of the fracture surface. The separated segments were kept in a beaker containing acetone and immediately placed in an ultrasonic unit tank containing water for sonication and operated at 40 kHz for 12 minutes. After that, the samples were mounted on a sample holder and analyzed under SEM. The files were microphotographed at different magnifications for the analysis of the fractured surface, the helical shaft at the site of fracture and the shape of the cross sections of the files under study. The images were recorded in a digital format.

Results

The mean values (results) of angular deflection at failure in degrees and number of cycles to fracture found in the file deformation test of the ProTaper F4 files were greater than those found for the WaveOne *Large* files. Table 1 shows these results, as well as the standard deviations for the two groups of files under study.

Mean and standard deviation of maximum load (gf) and torque at failure are shown in Table 2.

The values of toughness and torsional fracture were lower for WaveOne group than for the control group, as shown in Table 3.

Figures 6 and 7 show the calculated area using the mean values and standard deviations.

In the Vickers microhardness test, mean values and standard deviations of the WaveOne files were greater than those for the control group, as shown in Table 4.

SEM analysis revealed that the helical shafts of the files under study had different cross sections.

Figure 1. WaveOne Large file.

Figure 2. ProTaper F4 file.

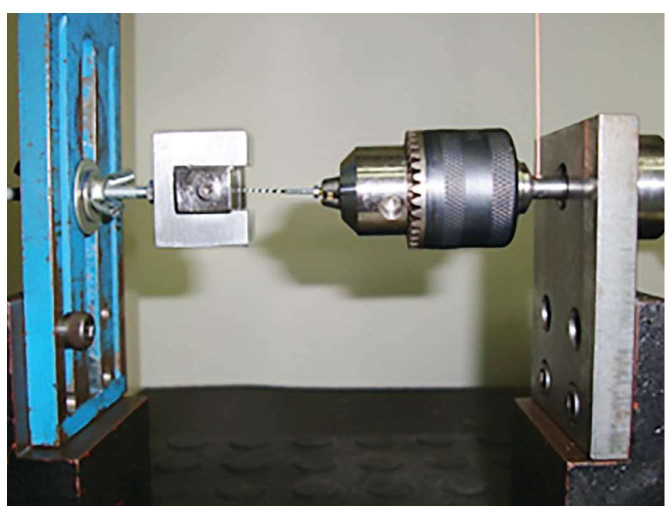

Figure 3. Photo of assembly used to apply torsional loads.

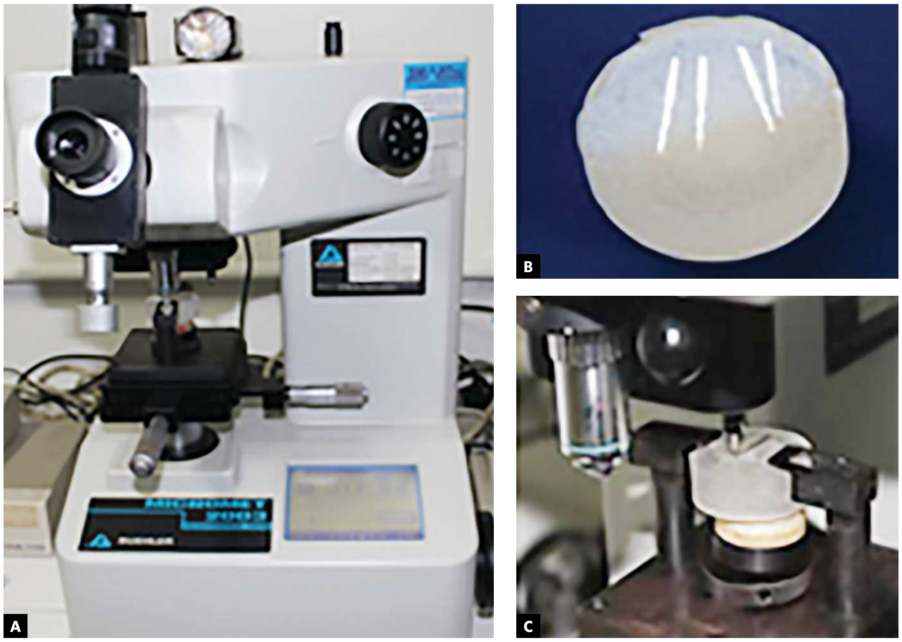

Figure 4. Micromet 2003 microindentation hardness tester (**A**) specimen embedded in resin plate (**B**); specimen positioning (**C**).

Figure 5. SEM unit: Quanta FEG 250.

After the torsional tests, the fracture surface at the point where the files were clamped had ductile characteristics, and the plastic deformation of the helical shafts showed inversion of spiral direction at the clamping point.

The helical shafts of the files under study had different cross sections (Figs 8 and 9).

After the torsional tests, the fracture surface at the point where the files were clamped showed ductility, and the plastic deformation of the helical shafts showed reversion of spiral direction at the clamping point. Surface finishing defects resulting from the machining process were also found in the files under study (Figs 10, 11 and 12).

Table 1. Mean angular deflection at failure and standard deviation of maximum deformation.

Files	No. of files	Maximum deformation (mm)	Maximum angle (degrees)	Maximum angle (turns)	SD (mm)
WaveOne Large	10	44	609	1.7	**7.56**
ProTaper F4	10	65	**900**	**2.5**	5.67

Table 2. Mean maximum load and torque at failure.

Files	No. of files	Maximum force (gf)	Maximum torque (gf.mm)	SD (N)
WaveOne Large	10	**679**	**2818**	0.50
ProTaper F4	10	574	2381	**0.55**

Table 3. Mean values and standard deviation of toughness to torsion (stress-strain) (N.mm) and J (Joules).

	WaveOne Large	ProTaper F4
Toughness (N.mm)	181.89	**217.78**
Toughness (J)	0.18	**0.22**
Mean (N.mm)	181.8	**217.7**
Mean (J)	38.3	27.02
SD (N.mm)	38.3	27.02
SD (J)	0.04	0.03

Table 4. Mean Vickers microhardness value and standard deviation.

NiTi alloy	Mean	SD
M-Wire	**356.12**	**36.18**
Conventional	279.14	11.75

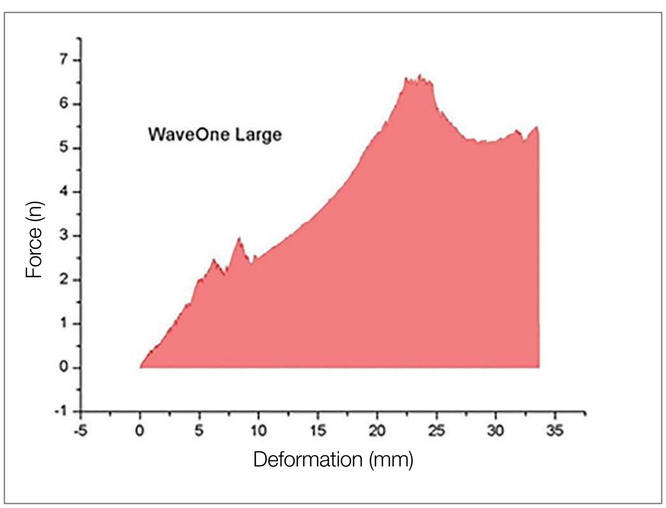

Figure 6. Mean toughness of WaveOne Large files.

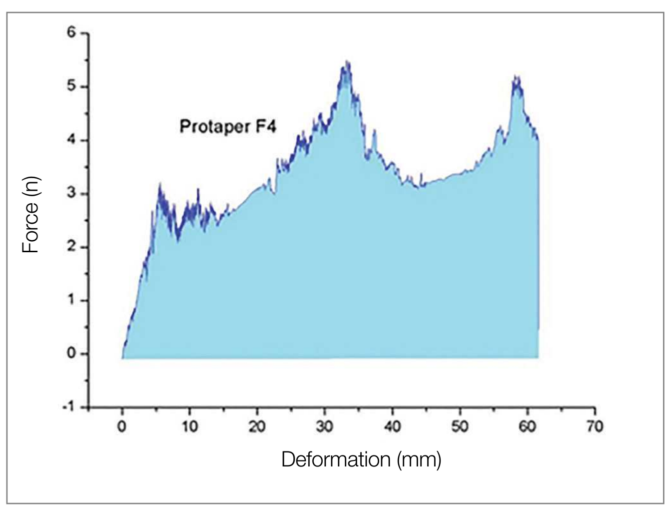

Figure 7. Mean toughness of ProTaper F4 files.

Discussion

The files under study had the same initial tip diameter (D0), different cross sections and the same indication of use, that is, the instrumentation of the apical third of a root canal. This study compared the resistance to torsion (torque at failure), toughness and hardness of two engine-driven NiTi endodontic files: WaveOne *Large* and ProTaper F4. These two files are made of different alloys: NiTi *M-Wire* for WaveOne and conventional NiTi for ProTaper. Their helical shaft taper is also different: 0.08 mm/mm for WaveOne Large, the study group, and 0.06 mm/mm for ProTaper F4 files, selected for the control group.

Torsional fracture may result when the tip, or another segment of the file, binds to or locks in the dentin wall of the canal while the shaft continues rotating. This explains why torsional fracture may occur in a straight root canal.[10]

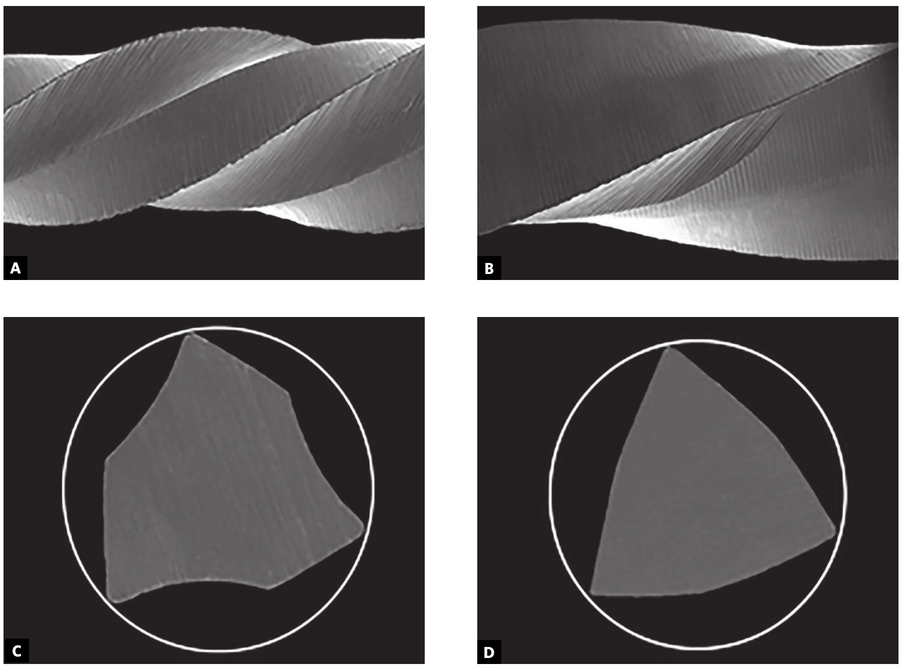

Figure 8. WaveOne Large file. Helical cutting shaft (**A**, **B**). Cross section of helical cutting shaft (100x magnification) (**C**, **D**).

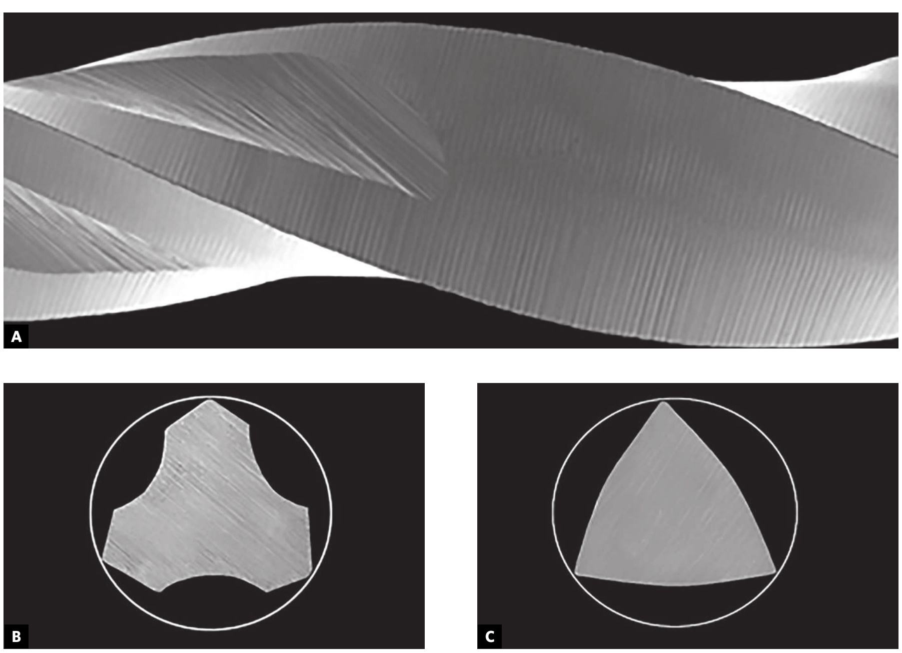

Figure 9. ProTaper F4 file. (**A**) helical cutting shaft; (**B** and **C**) cross sections along cutting shafts (100x magnification).

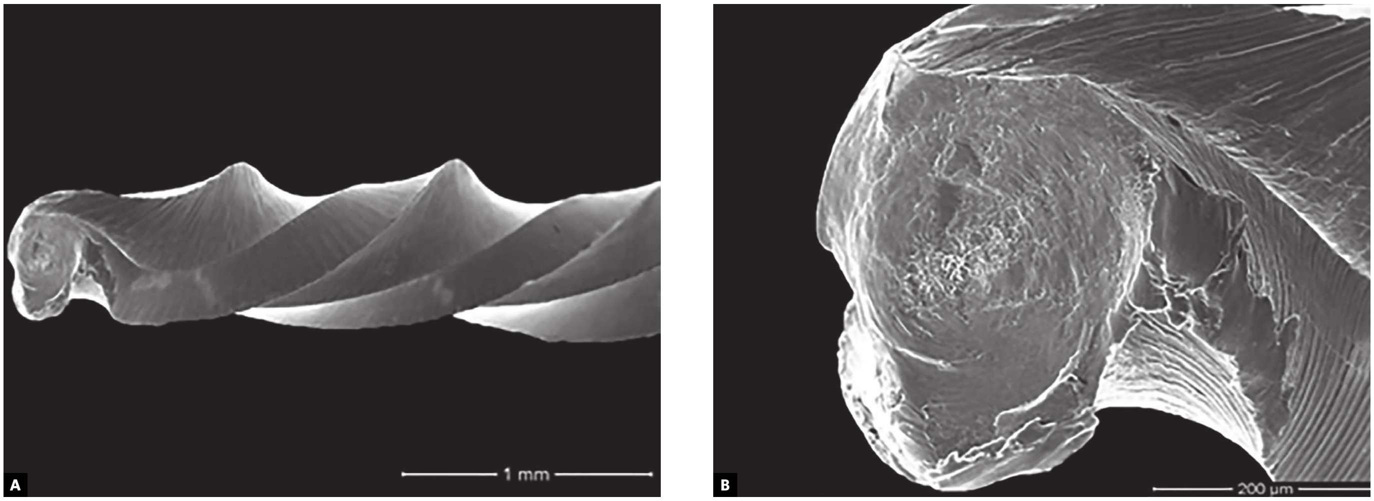

Figure 10. A) Helical shaft plastic deformation - WaveOne Large file (100x magnification). **B**) Fracture surface and spiral reversion at fracture site (500x magnification).

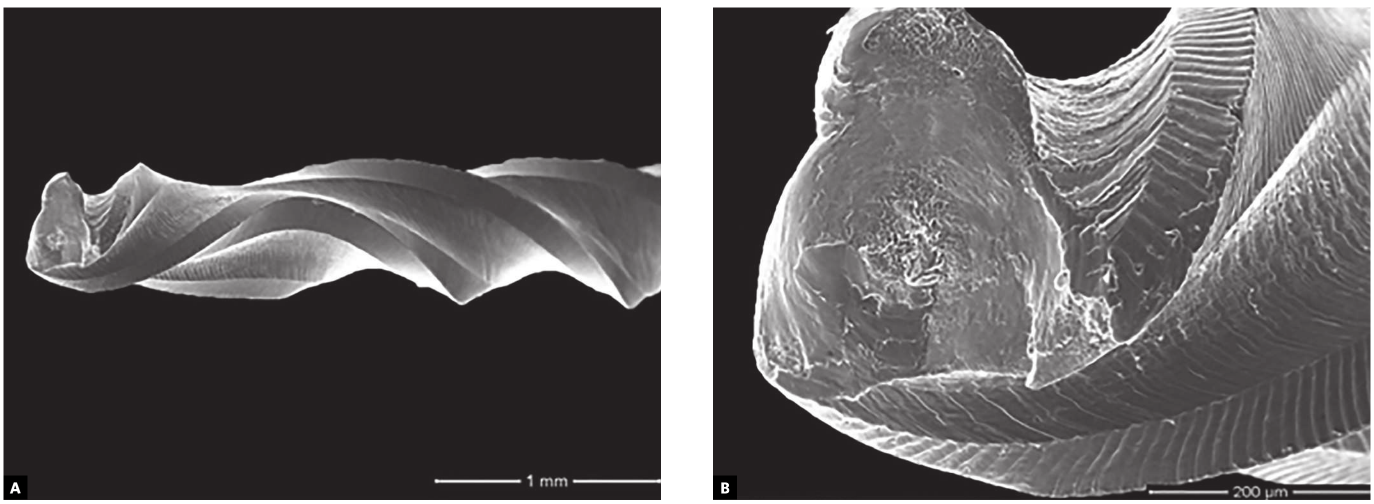

Figure 11. A) Helical shaft plastic deformation - ProTaper F4 file (100x magnification). **B**) Fracture surface and spiral reversion at fracture site (500x magnification).

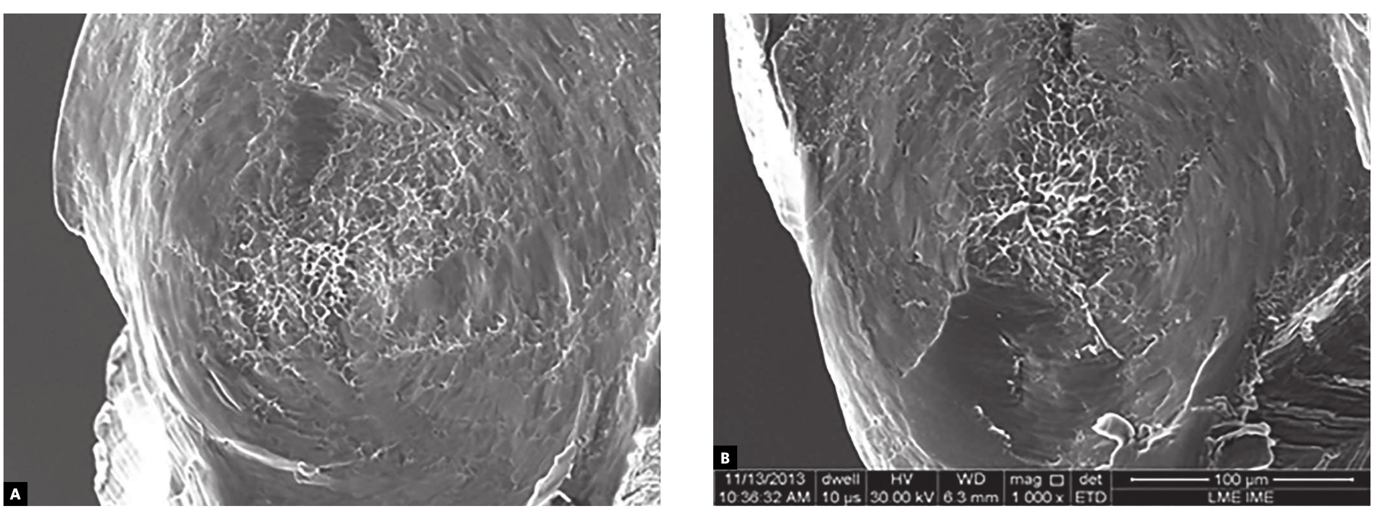

Figure 12. Ductile fracture surface: **A**) WaveOne Large; **B**) ProTaper F4 file (1000x magnification).

During torsional tests, first the material undergoes elastic deformation. When the load is greater than the elastic limit of the material under torsion, the helical shaft of the file undergoes plastic deformation, which results in the reversion of spiral direction. As plastic deformation increases, the metal alloy becomes harder, which increases the material's mechanical resistance. As the load continues to be applied, shear bond stress may surpass the file's limit of resistance to torsion, which leads to fracture.[8,11]

The main parameter under evaluation during torsional tests of endodontic files should be angular deflection at failure, and not torque at failure. The greater the deflection angle, the greater the elastic and plastic deformation at failure. According to several authors,[12,13,14] this parameter is a safety factor, because the torque applied is below the limit of resistance to torsional fracture (torque at failure).

The results of this study show that angular deflection at failure was statistically greater in the group of ProTaper F4 files than in the WaveOne group. This finding may be associated with the lower taper and, consequently, smaller diameter at D3 of the ProTaper F4 files. However, studies conducted by Gambarini[15], Svec and Power[16] and Bahia[17] did not find any direct association between the values of angular deflection at failure and file taper.

The results of torque at failure revealed that WaveOne files were more resistant to torsional fracture than the ProTaper F4 files. This result may be associated with the D3 diameter of WaveOne files, when compared with the same diameter for ProTaper F4 files. This finding is in agreement with those reported in the literature by Wolcott and Himel[18], Sattapan et al.[19], and Guikford et al.[20] The nature of the alloy would suggest that angular deflection of WaveOne files should be greater than that of ProTaper files, but this was not the case in this study. These results may be explained by the different shapes and areas of file cross sections, as well as the different taper along the tapering helical shafts.

WaveOne files absorb less energy to reach the point of torsional fracture, which is explained by the greater hardness of their alloy and may translate into greater torque. Greater toughness explains why ProTaper F4 files have better shear bond strengths, as confirmed by their angular deflection at failure. The greater capacity to absorb energy of the ProTaper F4 files is in agreement with the lower hardness of their alloy.

The mean microhardness values in the WaveOne group were greater than those found for ProTaper files, and this difference was statistically significant. The greater torque found in the WaveOne group may be associated with the greater values of Vickers microhardness of the NiTi *M-Wire* alloy. The cross section of the WaveOne and ProTaper F4 files underwent changes, which may have affected our results.

In Dentistry, the methods used to measure hardness or microhardness are the Knoop (Hard-Knoop: Hk) and the Vickers (Hard-Vickers: Hv) tests. Hk and Hv values found according to the hardness scales used for each method are practically equivalent. Microhardness is a dimensionless value or number, that is, a number that has no physical unit to define it and is, therefore, a pure number.

SEM analysis revealed that both metal alloys were ductile at the fracture site, with microcavities (dimples) of diverse shapes.

Plastic deformation of the helical shaft close to the file clamping point, confirmed by the reversion of the original direction of the spirals, was assigned to the loads applied in the opposite direction of the spirals, that is, counterclockwise for WaveOne and clockwise for ProTaper F4. This may be explained by the fact that the WaveOne spirals move clockwise, differently from the ProTaper F4 spirals. Both types of files have similar cross sections at the clamping point.

The clinical relevance of this study lies in the fact that it evaluated the mechanical behavior of WaveOne, an endodontic file recently launched in the market. Although more recently developed, WaveOne safety, when compared with that of ProTaper files, did not meet expectations. Because of its greater toughness and greater angular deflection at failure, ProTaper F4 seems to be safer clinically.

Our findings suggest that further studies should be conducted to investigate the mechanical behavior of WaveOne files in relation to torsional fracture, toughness and microhardness.

Conclusion

This study found that:

1. The NiTi *M-Wire* alloy had greater Vickers microhardness values than the conventional NiTi alloy.
2. ProTaper F4 files had greater toughness and greater angular deflection at failure than WaveOne files.
3. Torque at failure was greater for files in the NiTi *M-Wire* group than for the conventional NiTi files.
4. The fracture surface in both groups was ductile, and the spirals showed plastic deformation at the clamping point. The helical shaft of the files under study had different cross sections.

References

1. Lopes HP, Siqueira JF Jr, Elias CN. Preparo químico-mecânico dos canais radiculares. In: Lopes HP, Siqueira JF Jr. Endodontia: Biologia e técnica. 3ª ed. Rio de Janeiro: Guanabara Koogan; 2010. p. 415-79.
2. Siqueira JF Jr, Rôças IN. Clinical implications and microbiology of bacterial persistence after treatment procedures. J Endod. 2008 Nov;34(11):1291-301.e3.
3. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod. 2004 Aug;30(8):559-67.
4. Schäfer E, Schulz-Bongert U, Tulus G. Comparison of hand stainless steel and nickel titanium rotary instrumentation: a clinical study. J Endod. 2004 June;30(6):432-5.
5. Chen JL, Messer HH. A comparison of stainless steel hand and rotary nickel-titanium instrumentation using a silicone impression technique. Austr Dent J. 2002;47(1):12-20.
6. Yared G. Canal preparation using only one NiTi rotary instrument: preliminary observations. Int Endod J. 2008 Apr;41(4):339-44. Epub 2007 Dec 12.
7. Versluis A, Kim HC, Lee W, Kim BM, Lee CJ. Flexural stiffness and stresses in nickel-titanium rotatory files for various pitch and cross-sectional geometries. J Endod. 2012 Oct;38(10):1399-403.
8. Elias CN, Lopes HP. Materiais dentários. Ensaios mecânicos. São Paulo: Ed. Santos; 2007.
9. American Dental Association. Specification N° 28 Root Canal Instruments: General Requirements. Chicago: ADA; 1982.
10. Lopes HP, Elias CN, Siqueira JF Jr. Instrumentos endodônticos. In: Lopes HP, Siqueira JF Jr. Endodontia: biologia e técnica. 3ª ed. Rio de Janeiro: Guanabara Koogan; 2010. p. 305-413.
11. Cheung SPG. Instrument fracture: mechanisms removal of fragment and clinical outcome. Endod Topics. 2007;16(1):1-29.
12. Seto BG, Nicholls JI, Harrington GW. Torsional properties of twisted and machined endodontic files. J Endod. 1990 Aug;16(8):355-60.
13. Rowan MB, Nicholls JI, Steiner J. Torsional properties of stainless steel and nickel-titanium endodontic files. J Endod. 1996 July;22(7):341-5.
14. Lopes HP, Elias CN, Vedovello GA, Bueno CE, Mangelli M, Siqueira JF Jr. Torsional resistance of retreatment instruments. J Endod. 2011 Oct;37(10):1442-5.
15. Gambarini G. Torsional and cyclic fatigue testing of ProFile NiTi rotary instruments. J Evolut Dent Smile. 1999;2:4-14.
16. Svec TA, Powers JM. Effects of simulated clinical conditions on nickel-titanium rotary files. J Endod. 1999;25(11):759-60.
17. Bahia MGA. Resistência à fadiga e comportamento em torção de instrumentos endodônticos de NiTi [tese]. Belo Horizonte (MG): Universidade Federal de Minas Gerais; 2004.
18. Wolcott J, Himel VT. Torsional properties of nickel-titanium versus stainless steel endodontic files. J Endod. 1997 Apr;23(4):217-20.
19. Sattapan B, Palamara JE, Messer HH. Torque during canal instrumentation using rotary nickel-titanium files. J Endod. 2000 Mar;26(3):156-60.
20. Guilford WL, Lemons JE, Eleazer PD. A comparison of torque required to fracture rotary files with tips bound in simulated curved canal. J Endod. 2005 June;31(6):468-70.